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INDUCTANCE

Experiments investigating the unique behavioral characteristics of inductance led to the invention of the transformer.

EO 1.1 **DESCRIBE how current flow, magnetic field, and stored energy in an inductor relate to one another.**

EO 1.2 **DESCRIBE how an inductor opposes a change in current flow.**

EO 1.3 **Given a circuit containing inductors, CALCULATE total inductance for series and parallel circuits.**

EO 1.4 **Given an inductive resistive circuit, CALCULATE the time constant for the circuit.**

Inductors

An inductor is a circuit element that will store electrical energy in the form of a magnetic field. It is usually a coil of wire wrapped around a core of permeable material. The magnetic field is generated when current is flowing through the wire. If two circuits are arranged as in Figure 1, a magnetic field is generated around Wire A, but there is no electromotive force (EMF) induced into Wire B because there is no relative motion between the magnetic field and Wire B.

If we now open the switch, the current stops flowing in Wire A, and the magnetic field collapses. As the field collapses, it moves relative to Wire B. When this occurs, an EMF is induced in Wire B.

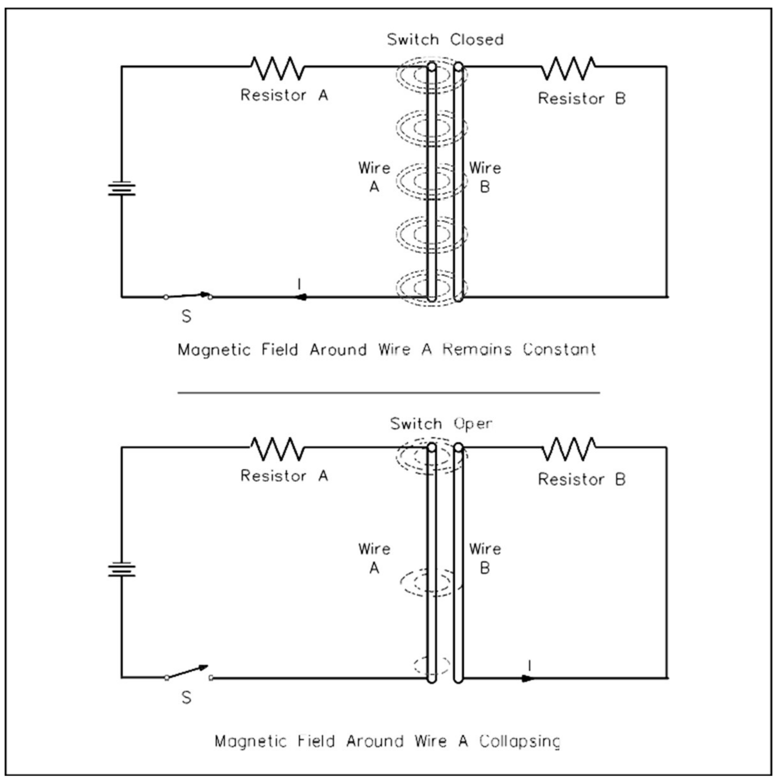

Figure 1 Induced EMF

This is an example of Faraday's Law, which states that a voltage is induced in a conductor when that conductor is moved through a magnetic field, or when the magnetic field moves past the conductor. When the EMF is induced in Wire B, a current will flow whose magnetic field opposes the change in the magnetic field that produced it.

For this reason, an induced EMF is sometimes called counter EMF or CEMF. This is an example of Lenz's Law, which states that the induced EMF opposes the EMF that caused it.

The three requirements for inducing an EMF are:

1. a conductor,
2. a magnetic field, and
3. relative motion between the two.

The faster the conductor moves, or the faster the magnetic field collapses or expands, the greater the induced EMF. The induction can also be increased by coiling the wire in either Circuit A or Circuit B, or both, as shown in Figure 2.

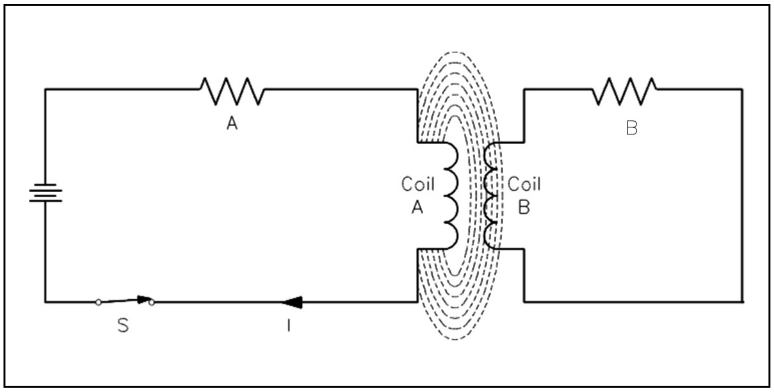

Figure 2 Induced EMF in Coils

Self-induced EMF is another phenomenon of induction. The circuit shown in Figure 3 contains a coil of wire called an inductor (L). As current flows through the circuit, a large magnetic field is set up around the coil. Since the current is not changing, there is no EMF produced. If we open the switch, the field around the inductor collapses. This collapsing magnetic field produces a voltage in the coil. This is called self-induced EMF.

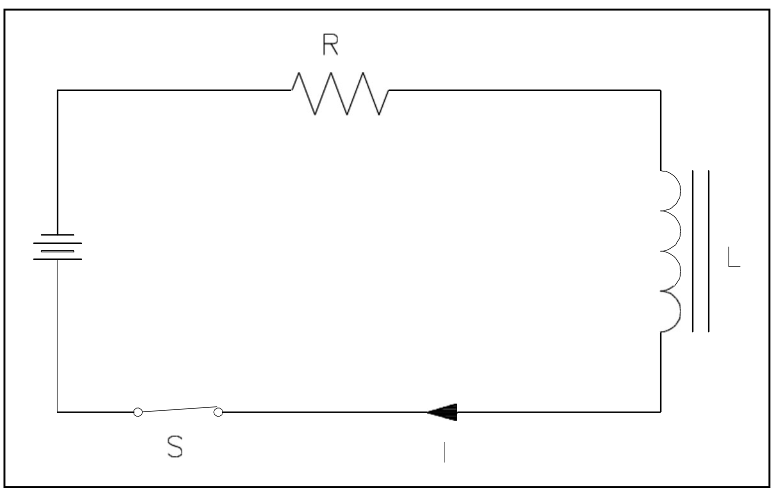

Figure 3 Self-Induced EMF

The polarity of self-induced EMF is given to us by Lenz's Law. The polarity is in the direction that opposes the change in the magnetic field that induced the EMF. The result is that the current caused by the induced EMF tends to maintain the same current that existed in the circuit before the switch was opened. It is commonly said that an inductor tends to

The induced EMF, or counter EMF, is proportional to the time rate of change of the current. The proportionality constant is called the "inductance" (L). Inductance is a measure of an inductor's ability to induce CEMF. It is measured in henries (H). An inductor has an inductance of one henry if one amp per second change in current produces one volt of CEMF, as shown in Equation (3-1).

$$CEMF = -L \frac{\Delta I}{\Delta t} \tag{3-1}$$

where

$CEMF$ = induced voltage (volts)

L = inductance (henries)

$\frac{\Delta I}{\Delta t}$ = time rate of change of current (amp/sec)

The minus sign shows that the CEMF is opposite in polarity to the applied voltage.

Example: A 4-henry inductor is in series with a variable resistor. The resistance is increased so that the current drops from 6 amps to 2 amps in 2 seconds. What is the CEMF induced?

$$CEMF = -L \frac{\Delta I}{\Delta t}$$

$$= -4 \left(\frac{2A - 6A}{2} \right)$$

$$= -4(-2)$$

$$CEMF = +8 \text{ volts}$$

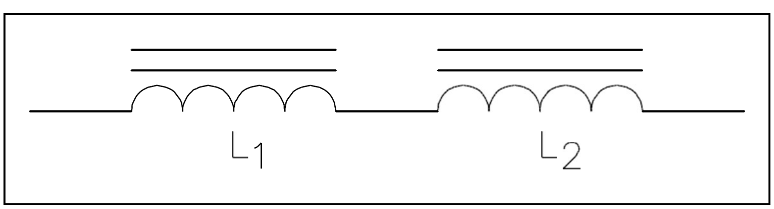

Figure 4 Inductors in Series

Inductors in series are combined like resistors in series. Equivalent inductance (L_{eq}) of two inductors in series (Figure 4) is given by Equation (3-2).

$$L_{eq} = L_1 + L_2 + \ldots L_n \tag{3-2}$$

Inductors in parallel are combined like resistors in parallel as given by Equation (3-3).

$$\frac{1}{L_{eq}} = \frac{1}{L_1} + \frac{1}{L_2} + \cdots \frac{1}{L_N} \tag{3-3}$$

When only two inductors are in parallel, as shown in Figure 5, Equation (3-3) may be simplified as given in Equation (3-4). As shown in Equation (3-4), this is valid when there are only two inductors in parallel.

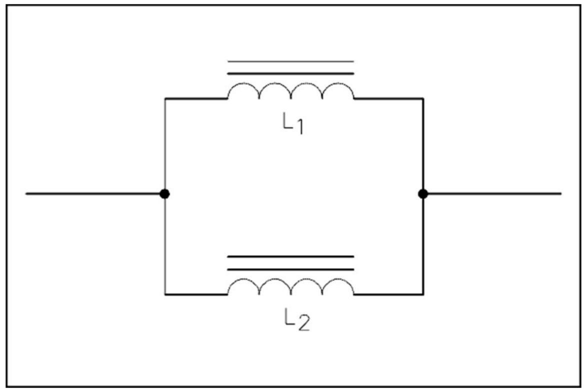

Figure 5 Inductors in Parallel

$$\frac{1}{L_{eq}} = \frac{L_1 L_2}{L_1 + L_2} \tag{3-4}$$

Inductors will store energy in the form of a magnetic field. Circuits containing inductors will behave differently from a simple resistance circuit. In circuits with elements that store energy, it is common for current and voltage to exhibit exponential increase and decay (Figure 6).

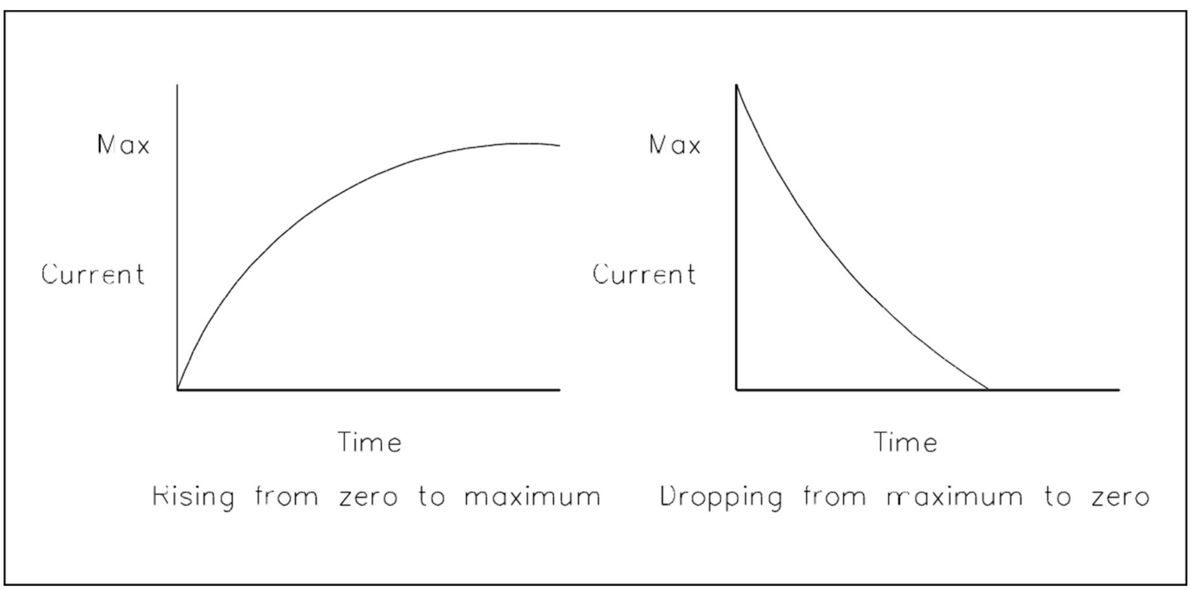

Figure 6 DC Current Through an Inductor

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